# Novel Algorithms for Cardiovascular Parameters' Estimation for Long Term Monitoring Systems

By

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# CERTIFICATE OF AUTHORSHIP/ORIGINALITY

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Candidate

**MOHA'MED ODEH AL-JAAFREH**

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## Publications arising from this thesis

### Book Chapters:

1. Adel A. Al-Jumaily and Moha'med O. Al-Jaafreh, *Multi – Agent System Concepts: Theory and Application Phases*, Chapter 19 in Book: Mobile Robots: Moving Intelligence, Edit by: Jonas Buchli, ARS International, pp.: 369-392, 2006.
2. Moha'med O. Al-Jaafreh and Adel A. Al-Jumaily, *Blood Pressure Estimation with Considering of Stroke volume Effect*, Encyclopedia of HealthCare Information Systems, N. Wickramasinghe and E. Geisler, Eds.: Idea Group Inc. (IGI Global), pp.: 965-971, 2008.

### Conference Papers:

3. Moha'med O. Al-Jaafreh and Adel A. Al-Jumaily, "Type-2 Fuzzy System Based Blood Pressure Parameters Estimation," *2nd Asia International Conference on Modelling and Simulation (AMS 2008)*, May 13 – 15, 2008, Kuala Lumpur, Malaysia, pp.: 953-958, 2008.
4. Usman Mahmood, Adel A. Al-Jumaily and Moha'med O. Al-Jaafreh, "Type-2 Fuzzy Classification of Blood Pressure Parameters", *The third International Conference on Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP 2007)*, December 3-6, Melbourne, Australia, pp.: 595 – 600, 2007.
5. Moha'med O. Al-Jaafreh and Adel A. Al-Jumaily, "Training Type-2 Fuzzy System by Particle Swarm Optimization", *IEEE Congress on Evolutionary Computation (CEC 2007)*, September 25-28, Singapore pp.: 3442-3446, 2007.

6. Moha'med O. Al-Jaafreh and Adel A. Al-Jumaily "Blood Pressure Estimation by Particle Swarm Optimization" *Cairo International Biomedical Engineering Conference 2006 (CIBEC'06)*, December 21-24, Cairo, Egypt, 2006.
7. Moha'med O. Al-Jaafreh and Adel A. Al-Jumaily, "Practical Swarm Optimization based Stroke Volume Influence on Mean Arterial Pressure", *The International Conference in Biomedical and Pharmaceutical Engineering 2006 (ICBPE 2006)*, 11th-14th December, Singapore, pp.: 508-511, 2006.
8. Gazi M. Azmal, Adel A. Al-Jumaily and Moha'med O. Al-Jaafreh, "Continuous Measurement of Oxygen Saturation Level using Photoplethysmography Signal", *The International Conference in Biomedical and Pharmaceutical Engineering 2006 (ICBPE 2006)*, 11th-14th December, Singapore, pp.:504-507, 2006.
9. Moha'med O. Al-Jaafreh and Adel A. Al-Jumaily "New Model to estimate Mean Blood Pressure by Heart Rate with Stroke Volume changing influence", *28th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (IEEE EMBC 2006)*, August 31 - September 3, 2006, New York, USA, pp.:1803-1805, 2006.
10. Moha'med O. Al-Jaafreh and Adel A. Al-Jumaily, " Multi-Agent System for Estimation of Cardiovascular Parameters", *1st International conference on Computers, Communications, and Signal Processing, with special track on Biomedical Technology (CCSP 2005)*, 14-16 Nov, Kuala Lumpur, Malaysia, pp.: 296-299, 2005.
11. Adel A. Al-Jumaily, Joseph M. Azzi and Moha'med O. Al-Jaafreh "Novel Algorithm in Multi-agent Collaboration on Solving Pursuit Problem", *Proceedings of the 2nd International Conference on Mechatronics (ICOM'05)*, 10-12 May, Kuala Lumpur, Malaysia, pp.: 124- 131, 2005.

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## List of Abbreviations (Acronyms)

| | |
|---|---|
| ABP | Arterial Blood Pressure |
| AHA | American Health Association |
| AC | Alternated Current |
| BPP | Blood Pressure Parameters |
| BP | Blood Pressure |
| B&A | Bland & Altman Plot |
| CPLTMS | Cardiovascular Parameters Long Term Monitoring System |
| CO | Cardiac output |
| DBP | Diastolic Blood Pressure |
| DC | Direct Current |
| ECG | Electric cardio graph |
| EDBP | Estimated Diastolic Blood Pressure |
| EIP | Electrical Impedance Plethysmography |
| EMAP | Estimated Mean Arterial Blood Pressure |
| ESBP | Estimated Systolic Blood Pressure |
| $HbO_2$ | Oxy-hemoglobin |
| Hb | De-Oxy-hemoglobin |
| HR | Heart rate |
| Hz | Hertz (frequency unit) |
| I | Circuit Current |
| IT2FS | Interval Type 2 Fuzzy System |
| LED | Light Emitting Diode |
| MAP | Mean Arterial blood Pressure |
| MF | Membership Function |

| | |
|---|---|
| ml | mile litre |
| mmHg | mile meter of Mercury (pressure unit) |
| MPSO | Multi-Particle Swarm Optimization |
| OS | Oxygen Saturation |
| PMF | Primary Membership Function |
| PPG | Photo-Plethysmography |
| PSO | Particle Swarm Optimization |
| SBP | Systolic Blood Pressure |
| SD | Standard Deviation |
| sec | Second |
| $S_pO_2$ | Oxygen Saturation |
| SV | Stroke Volume |
| T1FS | Type 1 Fuzzy System |
| T2FS | Type 2 Fuzzy System |
| TPR | Total Peripheral blood vessel's Resistance |
| V | Velocity |

## Abstract

In daily life every person needs continuous monitoring of temperature, heart rate, oxygen saturation level, blood pressure parameters and other parameters to have some idea about one's body systems performance and to assist doctors to diagnose one's health status. This information is more necessary for aged and unhealthy people, while it is also necessary for healthy person, who represents the undiagnosed subject.

Usually, the healthy and unhealthy subjects are advised to measure their cardiovascular parameters at home at various times in a day to avoid any bad developments for their health status. Available self-measurement devices give only discrete readings and have not provided accurate information of heart rate, oxygen saturation level, and blood pressure parameters in many situations since most of them do not consider the body's movement or the uncertainty associated with the reading.

Moreover, Blood pressure parameters (BPP): Systolic, Diastolic, and Mean Blood Pressures, have some types of correlation with the heart rate. This relationship is nonlinear and has many levels of uncertainty. The Type-2 Fuzzy system has a capacity to deal with nonlinear and uncertainty systems. The estimate of Blood pressure parameters based on heart rate can be categorized under such systems that fuzzy system can deal with.

This thesis presents a novel algorithm to measure photo-plethysmography signal, heart rate and the oxygen saturation level and also to estimate BPPs for healthy and unhealthy subjects based on a prototype transducer, particle swarm optimization and type-2 Fuzzy System.

The measured values of heart rate, oxygen saturation level, systolic, diastolic and mean blood pressures by utilizing the novel algorithm are compared with the clinical readings of heart rate, oxygen saturation level, systolic, diastolic and mean blood pressure.

Very encouraging results have been achieved for estimating heart rate, oxygen saturation level, systolic, diastolic and mean blood pressures and the accuracy of estimated results for that parameters for healthy subjects, by our designed algorithm, are 99.53%, 98.91%, 97.76%, 91.81% and 96.43%, respectively.

Add to that, the accuracy of estimated results systolic, diastolic and mean arterial blood pressure for unhealthy subjects are 94.51%, 91.48% and 94.79%, respectively.

On the contrary, the mean arterial blood pressure is estimated based on same heart rate and existing algorithm. This algorithm can only estimate mean arterial blood pressure. The accuracy of estimated mean arterial blood pressure equals 53.83%.

The proposed model achieves very encouraging results; since all accuracies of the blood pressure parameters for unhealthy and healthy subjects are more than 91.4%. Moreover, the proposed algorithm can be utilized to determine heart rate, oxygen saturation level, systolic, diastolic and mean blood pressures.